

## COAL & POWER SYSTEMS



STRATEGIC PLAN &  
MULTI-YEAR PROGRAM PLANS

# EXECUTIVE SUMMARY

The Fossil Energy Coal and Power Systems (C&PS) Program is committed to ensuring that, as America enters the 21st century, we will continue to have the cleaner, more affordable, and secure energy needed to keep our economy growing strong and to provide valuable jobs for many generations to come. To achieve this vision, Fossil Energy's C&PS program plan focuses on developing advanced fossil energy technologies aimed at improving the biosphere and continuing the economic competitiveness of our Nation.

The plan is structured to meet our short-term, mid-term, and long-term needs for low-cost, reliable electricity and transportation fuels, culminating in the creation of a new fleet of energy facilities called Vision 21. This document contains the current C&PS Strategic Plan and the Multi-Year Program Plans of each product line.

The C&PS program will create significant public benefits in the evolving energy market. It supports the U.S. Department of Energy's (DOE's) mission and its strategic goals to develop and promote secure and competitive energy systems that minimize impacts on the U.S. and the global environment, and to deliver critical scientific understanding and technological innovations. The following pages outline program strategy and identify the issues, priorities, challenges, major activities, and projects required to attain goals and objectives.

The plan has been developed by the Office of Fossil Energy and the Federal Energy Technology Center, utilizing stakeholder input. It is linked with DOE's Integrated Natural Gas Strategic Plan through discussions of gas-powered generation.

Comments on the C&PS plan should be addressed to the Office of Fossil Energy, 1000 Independence Avenue, S.W., Washington, D.C. 20585.

## CONTENTS

● EXECUTIVE SUMMARY	1
● STRATEGIC PLAN	4
● MULTI-YEAR PROGRAM PLANS	24
● TECHNOLOGIES FOR EXISTING PLANTS	26
● NEAR- AND MID-TERM DEVELOPMENT AND DEMONSTRATION	33
● DISTRIBUTED GENERATION	56
● VISION 21	64
● CARBON SEQUESTRATION RESEARCH	74
● ADVANCED RESEARCH	80
● INTERNATIONAL	84

CLEAN, LOW-COST ENERGY  
FOR A STRONG ECONOMY  
AND HEALTHY ENVIRONMENT

BUILDING ON A SUCCESSFUL  
TRACK RECORD

The availability of affordable energy is now, and will continue to be, essential to our Nation's economic strength. Even with great advances in renewable energy use, energy forecasts agree that fossil fuels will be the dominant energy source for the foreseeable future. By 2020, we will rely on fossil fuel for 90% of our energy needs. The aim of the Coal and Power Systems (C&PS) Program is to see that this occurs in the most efficient manner and without harm to our environment. Our Nation is blessed with abundant natural gas and coal resources that can be used to maintain and increase our productivity and economic well being while meeting environmental protection goals.

The C&PS program of the U.S. Department of Energy (DOE), Office of Fossil Energy, develops advanced power generation and alternative fuel technology in partnership with industry. Increased efficiency, low-pollutant emissions, reduced cost for power generation, and ultra-clean transportation fuels from coal, natural gas, and biomass are key goals of the program.

C&PS-supported RD&D has already returned substantial benefits to consumers and taxpayers. These returns include affordable, cleaner, and more efficient powerplants that are now in use throughout the world. The potential for future returns is even greater as technologies that are nearly through the RD&D pipeline enter the marketplace. Building on this successful track record of partnerships with industry, the C&PS program is developing very clean electric power generation technologies that will be much more efficient than powerplants in use today.

The long-term strategic vision of the program is to create the ability to use coal and natural gas to produce transportation fuels and valuable chemicals jointly with electric power in a way that produces little or no pollutants and achieves efficiencies of up to 90%. Powerplant efficiency matters: one golf-ball-sized lump of coal can produce enough electricity to light a 100-watt light bulb for 75 minutes using a typical powerplant in operation today to make the electricity, 90 minutes using advanced units nearly ready to enter the marketplace, and 140 minutes using the high-efficiency technology in use when this vision is realized. It's not just that less fuel will be used to light a room; using less fuel reduces the amount of pollutants, solid waste, and greenhouse gases (carbon dioxide) that are produced when the light bulb is used. When efficiency is combined with advances in environmental controls, the result is a very clean, environmentally responsible means to generate electric power using fossil fuels. This is the Coal and Power Systems Program Vision 21.

SELECTED PROGRAM BENEFITS TO DATE

- ✓ Cumulative SO<sub>2</sub> scrubber costs reduced by \$50 billion through 1995, and overall SO<sub>2</sub> emissions down by 40% since 1970, even though coal use increased 85% during this period.
- ✓ Low-NO<sub>x</sub> burners and postcombustion controls that satisfy emissions-reductions requirements installed in 50% of U.S. coal-fired capacity at a small fraction of the cost of previously available technologies.
- ✓ Clean atmospheric fluidized-bed technology commercially deployed with \$8 billion in sales.
- ✓ More than 600 MW in integrated gasification combined-cycle (IGCC) plants installed in commercial service with:
  - 10% to 20% improvement in efficiency
  - 98% reduction in SO<sub>2</sub> emissions
  - 80% lower NO<sub>x</sub> emission rate than current requirements.
  - 20% lower CO<sub>2</sub> emissions
- ✓ Three coal-processing plants initiated that convert low-rank Western coal and high-sulfur Eastern coal into a product that meets environmental standards.
- ✓ New technologies have been demonstrated that improve the environmental performance of steel and cement processes.
- ✓ Cost reductions realized by consumers because of these accomplishments are important to the U.S. economy. The Nation will continue to reap these benefits well into the future. The overall economic value of even a small reduction in the cost of electricity is huge, considering that domestic electricity sales are forecast to total 3,877 billion kilowatt-hours in 2010.

Ultimately, the returns realized by this program will extend far beyond U.S. borders. Energy to fuel continued growth will come primarily from fossil fuels, particularly in rapidly developing nations, such as China and India, that are rich in coal reserves. Exporting cleaner, more efficient technologies will not only benefit the U.S. economy, but will help satisfy growing global demand and improve living standards while reducing greenhouse gas emissions and preventing pollution.

The Coal and Power Systems Program is addressing key environmental concerns, while being responsive to DOE strategies enhancing scientific understanding and promoting secure, efficient, and competitive energy systems.

FEDERAL

GOVERNMENT'S ROLE

DOE, in partnership with the private sector, invests in energy research to protect the Nation against risks to energy supplies and damage to the environment. These Federal investments are carefully focused on areas where there are large potential public-sector benefits; but financial rewards, given the significant risks involved, are not adequate to attract sufficient levels of private-sector investment.

DOE supports the development of technologies meeting public-sector needs, technologies that would otherwise emerge far more slowly, if at all. Currently, private industry is limiting its own long-term energy R&D largely because of uncertainty related to future regulations, the perceived need to minimize long-term capital investments, and risks relating to deregulation of the electric power industry.

Through co-investment with industry in promising technologies, DOE mitigates R&D risks. Active participation by DOE and industry partners in such R&D positions the U.S. as a leader in growing global markets for clean energy technologies.

PURSUING THE VISION

The Coal and Power Systems Program builds toward Vision 21. Each element has specified goals that align with the target of achieving market availability for Vision 21 technologies in the 2010 to 2015 time frame.

Near-term goals include development of improved technologies for existing plants, concentrating on cost-effective advanced environmental compliance for the Nation's current coal-fired powerplants. These technologies will also increase the efficiency of existing plants so that they can provide more economical power.

ENERGY FOR TRANSPORTATION

Net oil imports, which now account for 46% of U.S. consumption, are projected to increase to 65% by 2020. Growing dependence on imports, particularly from politically unstable regions, threatens our national energy security and contributes to a negative U.S. trade balance. High-quality transportation liquids from coal, natural gas, and biomass resources can offset these effects.

In the near- and mid-term, development of a new generation of advanced power and fuel-producing systems will be completed. The efficiency of these systems ranges from 40% to a potential 70%. Systems under development include technologies—such as advanced gas turbines and combined gasification/fuel-cell systems—that will become part of Vision 21 plants of the future.

Another element of the program is directed toward clean and reliable distributed generation systems. Modular construction and flexible siting make these systems desirable in specific market segments. Internationally, and in Alaska, distributed systems will be well-suited to applications in the many areas not served by an electrical transmission and distribution grid.

Carbon sequestration is an element of the program critical to the sustained or expanded large-scale use of fossil fuels with current generation technology. To substantially reduce total world greenhouse gas emissions, new CO<sub>2</sub> sequestration technologies are needed. Research targets longer-term solutions, including CO<sub>2</sub>-recycling, enhanced natural sinks for carbon, and geologic sequestration.

Advanced research pursues the underlying technology base for more efficient use of fossil resources. Efforts are focused on such areas as novel materials, bioprocessing, coal utilization science, university research, advanced hybrid processes and cycles, and smart systems, all of which will help achieve Vision 21 goals.

Development of strategic international partnerships is also an important part of the program. They foster environmental cooperation and facilitate global sales of U.S. energy technologies.

Systems studies shape the framework and scope of program strategy and provide information to stakeholders on vital energy and environmental issues.

FUTURE PROGRAM BENEFITS

Future benefits of the C&PS program include low-cost energy, superior environmental protection, long-range fuel supply security, economic competitiveness, and high-value jobs.

- Between 2000 and 2015, 70% reductions are projected for SO<sub>2</sub>, NO<sub>x</sub>, and HAPs emissions from existing powerplants.
- Environmental compliance cost reductions for meeting existing and future regulations are expected to average over \$5 billion/year through 2010, and could exceed \$7 billion/year after 2010.
- By 2010, savings in the cost of electricity are expected to increase the cumulative Gross Domestic Product (GDP) by \$137 billion, generating more than 1.4 million job years.
- Cost-competitive advanced technologies can by 2020 capture potential international sales of over \$235 billion, creating almost 500,000 jobs/year. Domestic sales are expected to bring \$65 billion, and generate over 100,000 jobs/year.
- A coal-conversion industry will reduce dependence on foreign oil, increasing oil security while helping reduce the U.S. energy trade deficit and capturing a share of what may be the largest new job-creating sector of the economy.
- By 2020, deployment of more efficient power systems *globally* could reduce greenhouse gas emissions by nearly 150 million metric tonnes (MMT) per year of carbon. The goal set for FE-sponsored sequestration options is to be able to offset all growth in U.S. carbon emissions beginning in 2015.



# STRATEGIC PLAN

## CONTENTS

● MISSION	6
● VISION TO 2015	6
● SITUATION ANALYSIS	6
● STRATEGIC GOALS— PLANNING HORIZON 2015	11
● PERFORMANCE INDICATORS	13
● PROGRAM STRATEGIES	18
● COAL AND POWER SYSTEMS TECHNOLOGY	19
● PROGRAM BENEFITS	22

MISSION

The mission of the Coal and Power Systems (C&PS) Research and Development (R&D) Program is to foster the development and deployment of advanced, clean, affordable fossil-based power and alternate fuels systems. Fuel-flexible power generation and conversion technologies will be developed to efficiently utilize coal, gas, and opportunity fuels. The long-term focus is on utilization of coal—our Nation’s most abundant energy resource. Through internal government research and external partnerships with industry and academic organizations, we will promote U.S. global leadership in coal fuels and power-systems technology, creating U.S. jobs and contributing to a stronger economy.

VISION TO 2015

Clean production of low-cost electricity and low-cost fuels from coal will raise global living standards for future generations.

As the leader in developing ultra-high-efficiency energy technologies with near-zero emissions, the United States will benefit from plentiful, low-cost electricity supplies and alternate fuel sources. The United States will produce a significant share of the products and services being used in the fast-growing world energy market while enhancing its trade balance, and creating highly skilled, well-paying jobs.

SITUATION ANALYSIS

PRESENT SITUATION

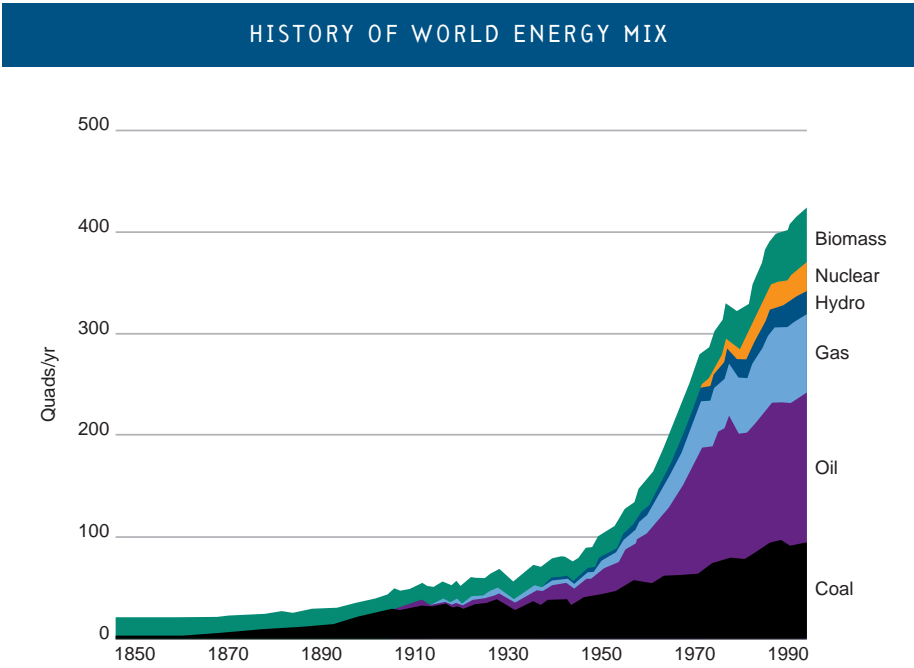
The U.S. has the lowest unsubsidized electricity rates in the world. Gas and coal prices are lower than in most of the world. The U.S. also has one of the most energy-intensive economies, consuming a quarter of the world’s total energy, while producing a quarter of the world’s GDP. One half of U.S. oil consumption is from imported oil. According to the Energy Information Administration (EIA), U.S. energy expenditures for 1996 were \$291 billion for petroleum products and \$214 billion for electric power. Within the electric-generation sector, fossil fuels provide 68% of the overall domestic need. Coal accounts for 55% of electricity needs and is expected to continue to fuel the majority of electric power production.

The U.S. trade balance for oil and natural gas was a negative \$63 billion in 1996. This amount is approximately equal to the top three export commodities (chemicals, agricultural products, and manufactured goods).

THE ROLE OF AN EFFICIENT AND CLEAN FOSSIL ENERGY CYCLE

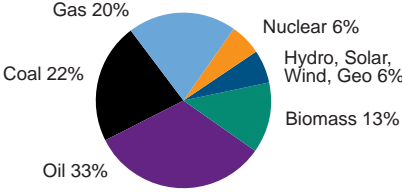
All countries desire adequate energy resources for current needs and future generations. For the U.S., fossil energy remains a major resource (greater than 85%) in the country’s mix of energy use. The challenge is to improve the efficiency of the fossil energy cycle in a clean, environmentally friendly manner.

*This graph shows the world’s primary energy supply for the past 150 years. The most noticeable feature is the 20-fold increase in energy use between 1850 and 1990. The energy mix has also changed. In 1850, biomass—wood—was the primary energy source. In 1990, fossil fuels—coal, oil, and natural gas—are the primary energy sources.*

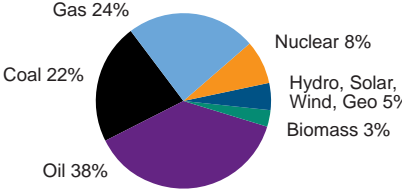


ENERGY CONSUMPTION BY FUEL TYPE

World



United States



**U.S. dependence on low-cost energy.** The continued strength of the U.S. economy depends on the availability of low-cost energy. The demand for electricity and transportation fuels will continue to grow. Fossil fuels will meet much of this demand.

Changes in electricity prices have significant effects on the economy. For example, an increase in the cost of electricity of 0.5 cents per kilowatt-hour (about a 7% increase in delivered price) leads to the same inflationary impact as a 30-cent-per-gallon rise in gasoline price (about a 25% increase in delivered price). Therefore, low-cost electricity is essential to economic growth.

However, Americans want secure energy supplies, and the associated economic benefits, achieved in an environmentally responsible manner. The goal of affordable energy that does not harm the environment can be achieved by the use of advanced, more efficient power generation and conversion systems.

STRATEGIC ISSUES AND DRIVERS

**Increased competition in the domestic power-generation industry.** Transforming a regulated power-generation industry into one that is market-driven creates uncertainties. As a result, industry is reluctant to risk major, long-term investments in generation facilities, especially those associated with advanced technologies having higher capital costs, even if they show improved environmental performance. Effective means are needed to overcome market entry barriers to these advanced technologies.

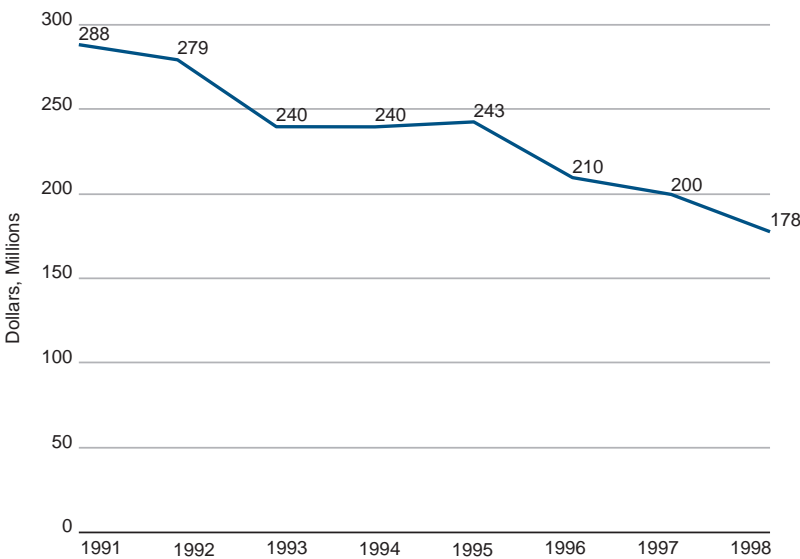
**Economic competitiveness.** Because other governments provide assistance to their industries, the Federal government must strive to ensure that U.S. industries are able to compete in the global market, and must support activities that effectively secure a “level playing field” for domestic suppliers.

*Today, the 5.9 billion people in the world use more than 400 quads of energy per year. Fossil fuels provide 75% of the world’s energy.*

**Environmental compliance with domestic regulations.** Given potential regulatory requirements for NO<sub>x</sub>, SO<sub>2</sub>, HAPs, ozone, fine particulates, and solid and liquid wastes, the Nation must find cost-effective ways to implement environmental protection regulations.

**Energy R&D trends and funding constraints.** R&D investments, including energy R&D, help drive economic growth and job creation, and are one of the most important foundations for U.S. economic competitiveness and international leadership. However, investments from both the private sector and the Federal government have declined significantly; this trend is expected to continue. Consequently, government resources must be leveraged with private-sector funds to achieve identified goals within the envisioned time frame.

FUNDING HISTORY



*Funding for C&PS is declining. Closer collaboration with private and public stakeholders has facilitated progress toward program goals.*

**Energy security.** World and U.S. oil demand continues to grow while U.S. oil production declines. This, coupled with the reality that a large percentage of oil resources are found in politically uncertain regions, means that the Nation must position itself with technologies that use domestic resources to produce transportation fuels to ensure its long-term energy and national security.

**Response to global climate concerns.** International concerns over the future impacts of greenhouse gases produced by anthropogenic activities have led to an international consensus that cost-effective measures to reduce the growth of greenhouse gas emissions are prudent. Some Nations remain concerned about the uncertainties of potential longer-term (2100 and beyond) impacts. Domestic and international sources are also pressing for large absolute reductions in the near-term. Technologies being developed to allow the use of domestic resources must address these concerns.

STAKEHOLDER CONSIDERATIONS

Public

The public's concerns include energy costs, system reliability, and the protection of health and the environment.

Utilities and other electricity generators

Utilities are concerned about proposed tougher environmental regulations. They are also concerned about the treatment of assets in which they invested as a "regulated" industry. In preparation for competition, some are providing other energy services, shedding assets, or entering into joint ventures, while others continue to operate as low-cost producers.

Equipment suppliers and energy service companies

Domestic growth in demand for electricity will be low. Thus, equipment suppliers see limited opportunities for new baseload capacity in the U.S. over the next 10 years. However, a large international market for electricity is

projected, especially in developing and transitional economies, and there is intense global competition for this market.

With few units contemplated domestically, and facing subsidized competition abroad, U.S. vendors and suppliers are unable to invest in longer-term R&D to develop improved systems without Federal government help.

Industry sector

The industry sector wants to be able to rely on stable energy prices and reliable supplies. Electricity-intensive industries see deregulation as a way to reduce their production costs. They are also concerned about availability, reliability, price stability, and power quality.

Regulatory agencies and oversight bodies

**Environmental Protection Agency (EPA).** The EPA is implementing more stringent environmental standards, intended to improve human health and

protect the environment as part of the Clean Air Act Amendments (CAAA) implementation. Further reduced standards on NO<sub>x</sub> emissions (as a precursor to ground-level ozone), lower caps on SO<sub>2</sub> emissions, tightened fine particulate emission requirements, and the introduction of new limits on hazardous air pollutants (e.g., mercury) are expected.

**Federal Energy Regulatory Commission (FERC).** FERC recently issued Orders 888 and 889 on equal access to the transmission of electricity as a way to increase competition. These orders, in effect, started a restructuring of the power industry.

Other government agencies

**U.S. Congress.** Congress is expected to debate the Administration's Comprehensive Electricity Competition Plan and to consider the uncertainties that increased competition will bring. As Congress seems determined to maintain projected balanced budgets, government investments in R&D may

become targets for reduced funding. Congress' concerns also extend to the effects of unfunded mandates, including added costs for compliance with increasingly stringent regulations, on the future domestic economy.

**Internal DOE.** Given the present funding constraints, the Energy Resources Business Line of DOE has competing priorities. Administration policy drivers for DOE focus on investments to improve and protect the environment, maintain energy security, and promote the economic well-being of the Nation. DOE is dedicated to ensuring that R&D is well-focused, and that it will return lasting public benefits many times greater than the initial investments. DOE also has a stake in ensuring that advanced technologies arising from R&D are effectively deployed to reap these public benefits.

**State and local governments.** Several State governments have already enacted legislation that supports increased competition in the power-generation industry. Much more is

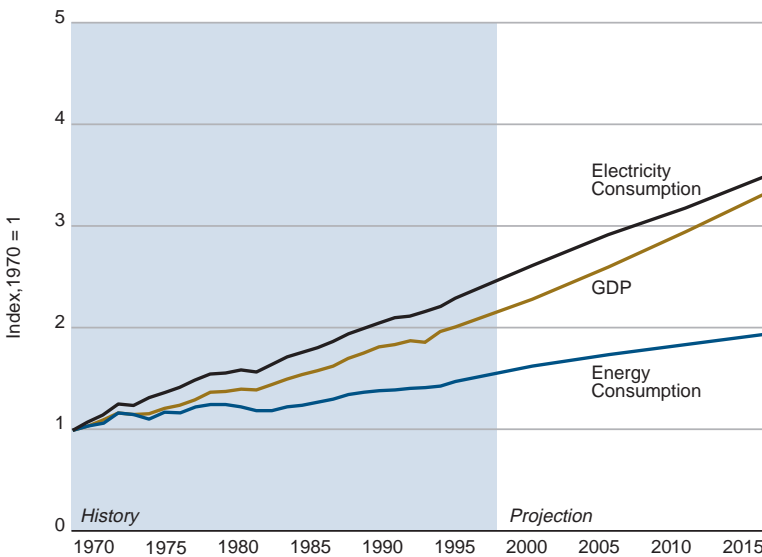
expected to follow. The drivers are (1) reduced cost of electricity to consumers and (2) the desire to retain current jobs and encourage future investments in their States.

Other considerations

International Energy Agency (IEA).

The 23 countries that comprise the IEA seek to create conditions in which the energy sectors of their economies can make the fullest possible contributions to sustain economic development, the well-being of their people, and a high-quality environment. Establishing free and open markets is a priority. Energy security and environmental protection are also emphasized through diversification of energy supply, cleaner and more efficient use of energy, and energy conservation. The IEA countries recognize the reality of global energy interdependence and promote the effective operation of international energy markets.

TRENDS IN ENERGY, ELECTRICITY, AND GDP



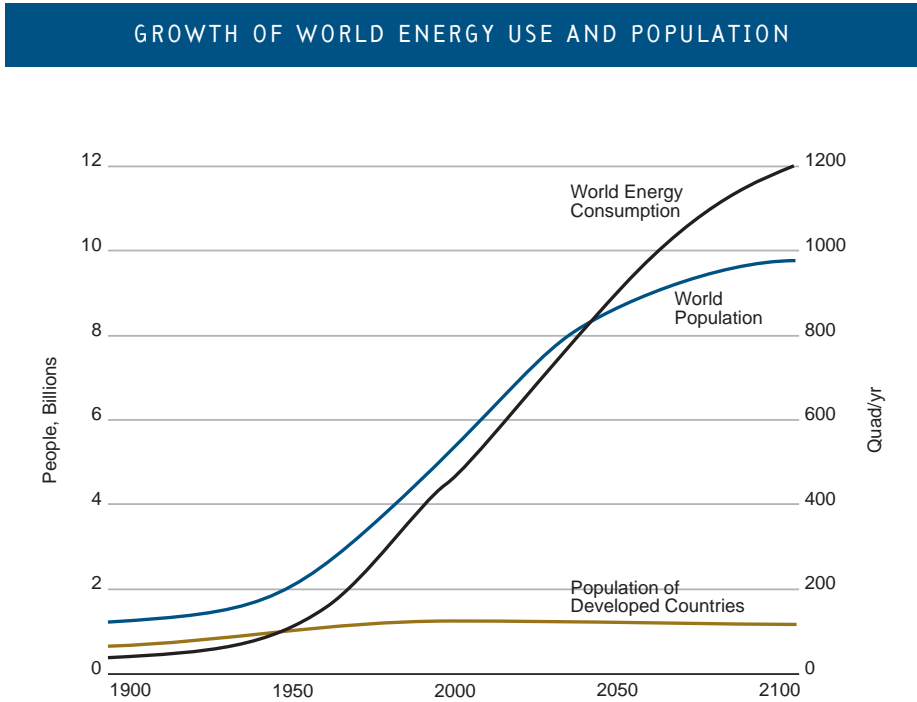
**Developing countries.** Developing countries include energy as a high-priority need along with food, clean water, and health and medical care. Many developing countries would like assistance with electrification. They believe they can benefit from a better understanding of advanced fossil systems, e.g., clean coal technologies. In addition to technical assistance and technology transfer, developing countries also want assistance in infrastructure development. Underdeveloped financial and regulatory systems often increase project risk in these countries. This means project financing by public- and private-sector organizations is challenging. In general, newly industrialized nations present unparalleled opportunities for applying U.S. expertise (resulting in U.S. sales) to build clean, reliable, and economical electric power systems.

FUTURE TRENDS

**Increased U.S. reliance on fossil fuels.** The DOE Energy Information Administration (EIA) projects that U.S. reliance on fossil fuels will rise from the present level of 85% to 90% by 2020 under current trends of price and usage. The EIA also projects that the use of fossil fuels to produce electricity will rise from the current 68% to 83% by 2020. Approximately 225,000 MW of new electricity generating capacity will be required by 2010. Of this, 50% will be gas-fired peaking units, and 40% will be gas combined cycle.

**U.S. oil and gas imports.** The United States is a declining oil producer and imports one-half of the 18.4 million barrels of oil consumed every day. The U.S. is also a net importer of natural gas. By 2020, it is expected that the Nation will import about 65% of its oil, a total of 16 million barrels per day, and 15% of its gas.

*Population is perhaps the most important factor in determining the future of energy use. Population is predicted to grow from 5.9 billion to 8 to 12 billion by 2100. This expanded world population will consume three times as much energy as we consumed in 1970.*



The dependence of the U.S. on imported fuels can be reduced through changes in the mode of transportation and the production of alternate fuels from coal or other sources.

**Increased world energy demand.** On a world scale, oil demand is expected to reach about 97 million barrels per day by 2010, or about 37% higher than today.

Economic growth, largely in developing countries, will fuel these increases in energy demand for oil.

**Decline in longer-range R&D funding.** Longer-range energy R&D, funded solely by private-sector entities, is expected to continue its decline as companies focus more on near-term research (6 months to 1 year) because of increasing competition.

*Fossil fuels currently are used to produce 68% of the Nation's electricity. That figure is expected to rise to 83% by 2020.*

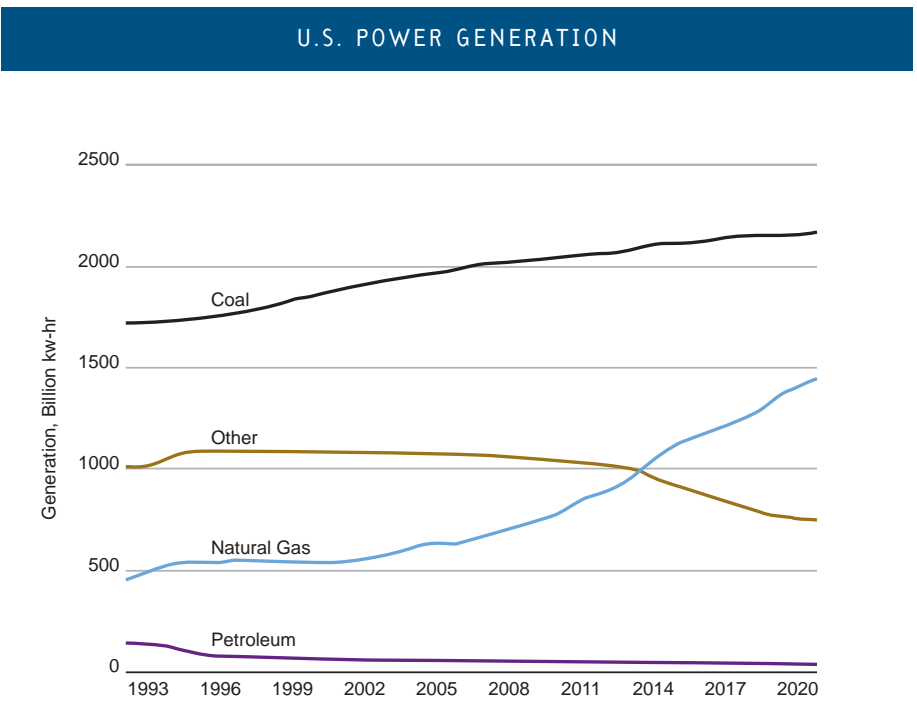
STRATEGIC GOALS –  
PLANNING HORIZON 2015

**DOE STRATEGIC ENERGY GOALS**

The Coal and Power Systems (C&PS) Program is an integral part of the Fossil Energy Strategic Plan and derives its goals and objectives from the goals of that plan. The Fossil Energy Strategic Plan in turn supports a key DOE strategic energy goal: promoting secure, competitive, and environmentally responsible energy systems that serve the public's needs. The C&PS program is also responsive to similar goals of the Comprehensive National Energy Strategy.

The C&PS program supports the following primary goals of the Fossil Energy Strategic Plan:

- **Environment.** Eliminate environmental issues as a barrier to fossil fuel



production and use, while maintaining the availability and affordability of fossil fuels.

- **Security.** Ensure the availability of secure, affordable liquid fuels.

Meeting these goals will yield sustained public benefits from the use of our abundant fossil resources.

**COAL AND POWER SYSTEMS PROGRAM GOALS**

Coal and Power Systems Program goals support the Fossil Energy environmental and security goals in the following ways:

**Environment**

- By 2010, make available cost-effective power systems, with negligible emissions of conventional pollutants and significantly reduced CO<sub>2</sub>, that achieve generating efficiencies greater than 60% using coal, 75% using natu-

ral gas, and over 85% in combined heat and power applications.

- During the 2003–2010 period, make available technologies for existing coal and power plants that will significantly lower the cost of meeting more stringent environmental regulations.
- During the 2005–2015 period, make available a suite of cost-effective options with increasingly large carbon sequestration capacity.

**Security**

- Provide the Nation with large, less-polluting alternative sources of liquid transportation fuels that are cost-competitive with equivalent petroleum products, for deployment beginning around 2010.

In addition, the C&PS program has the goals of:

- Promoting the export of U.S. fossil technology products, equipment, and services to create U.S. jobs, reduce the trade deficit, and reduce local, regional, and global environmental impacts.
- Helping to ensure the reliability of environmentally acceptable energy supplies by managing the regulatory review, as required by law, of certain export/import activities related to electricity.

#### Vision 21

The ultimate integration of the C&PS goals is a concept called Vision 21, which builds on the C&PS technology development portfolio. Vision 21 provides the technology for a new fleet of cost-competitive plants of varying sizes with ultra-high efficiency, near-zero pollutants, and fuel-flexible features. Some of these plants will be capable of integrating power generation with the production of a high-value slate of transportation fuels and chemicals for the market. Vision 21 plants will also have the option of using carbon sequestration systems to address global climate change issues.

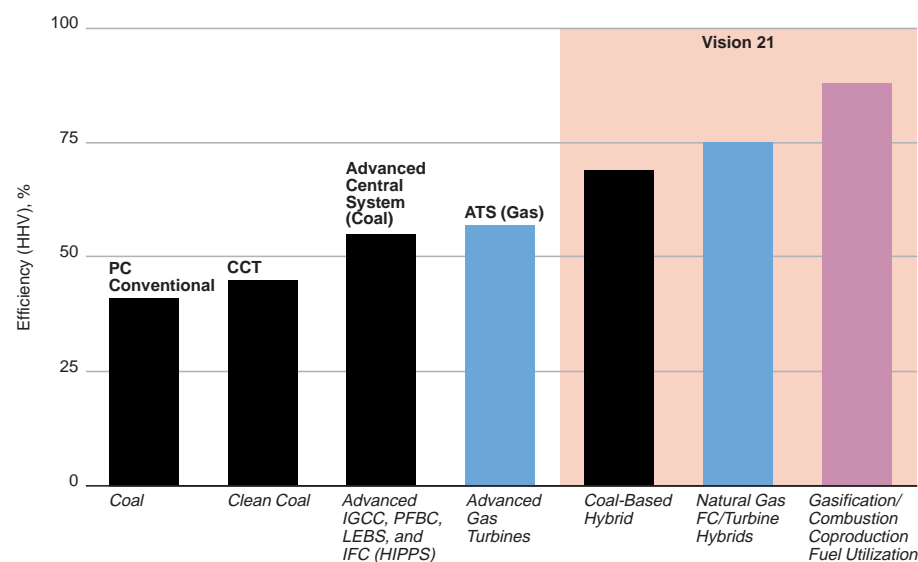
The distinguishing features of the Vision 21 fleet are:

- Production of low-cost electricity at stand-alone efficiencies of more than 60% for coal and over 75% using natural gas

- Near-zero pollutants to meet more stringent emissions standards (less than one-tenth of New Source Performance Standards [NSPS] for criteria pollutants) at a lower cost
- Options for no net CO<sub>2</sub> emissions
- Fuel flexibility (coal, natural gas, and opportunity fuels)
- A set of flexible, integrated modules configured to meet a range of market applications and sizes, and capable of producing electric power and an array of high-value commodities (such as chemicals, high-quality steam, liquid fuels, and hydrogen) at competitive prices in a free market

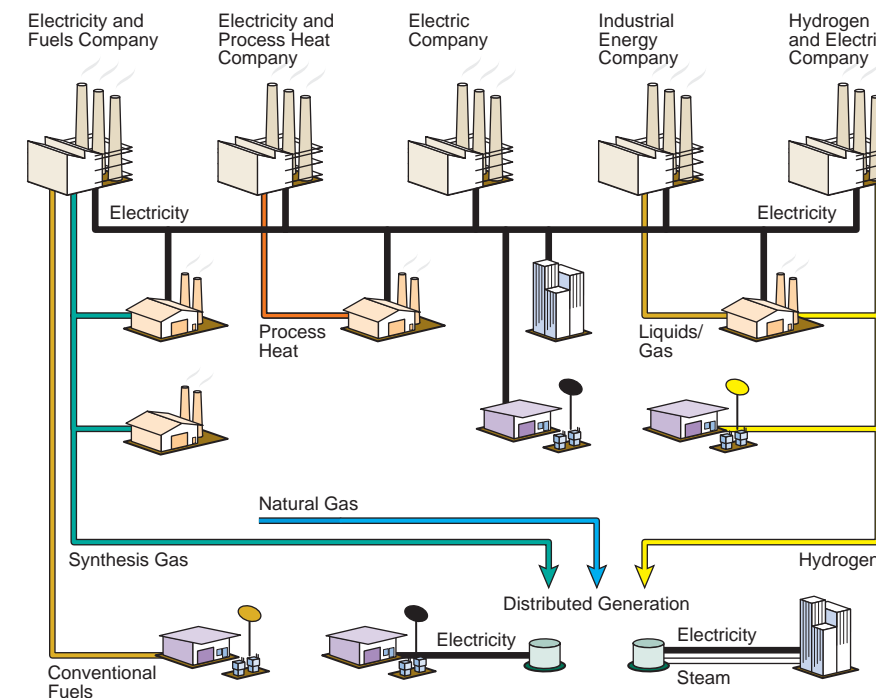
Specific objectives for the Coal and Power Systems Program elements in support of the goals are identified in the table on pages 14 and 15.

#### FOSSIL-BASED POWER AND ENERGY UTILIZATION



Conventional new powerplants operate at 35% to 37% efficiency. The Clean Coal Technology Program has already demonstrated plants with 38% to 40% efficiency. "Nth"-of-a-kind CCT units will improve to the 45% to 50% level. Vision 21 powerplants will be capable of 60% to 65% efficiency using coal, 75% efficiency using gas, and 85% efficiency in combined heat and power applications.

#### A VISION 21 FLEET FOR THE 21ST CENTURY



Vision 21 technologies are intended to support customer choice through a fleet of competitive plants. These highly efficient, near-zero-emissions systems can be optimized for a variety of private-sector needs. For example, an electric company Vision 21 plant would be configured to optimize the production of electricity; an industrial energy company would be configured to produce electricity and high-value liquids and gases, and a self-generator's system would be configured as a competitive source of electricity, heat, and perhaps hydrogen. Distributed generators could provide the same services in remote areas or alternative choices to customers in developed areas and also provide peaking capacity to the grids.

#### PUBLIC, CUSTOMER, AND STAKEHOLDER OUTREACH GOALS

DOE's outreach efforts are increasing public awareness of the importance of clean, low-cost fossil energy to sustain a high quality of life now and for future generations.

A goal of these outreach efforts is to seek input from the public and other stakeholders in order to properly fashion a program that meets their needs. These efforts highlight fossil energy's contribution to improved environmental quality, strong economic health, and continued national security.

Recommendations and suggestions on program emphasis and direction continue to be received from customer and stakeholder groups, such as the Coal Utilization Research Council, the Coal Industry Strategy Forum, the Gasification Technology Council, the Council of

Industrial Boiler Owners, and the Gas Turbine Association; from State agencies; and from advisory groups such as the National Coal Council. These strong outreach activities will improve the acceptance of fossil fuel, particularly coal, as an environmentally acceptable source of energy.

#### PERFORMANCE INDICATORS

##### DEFINITION OF OUTCOME-ORIENTED METRICS

**Benefits** are the overall value to the public resulting from the program investment in R&D. Types of benefits include lower-cost energy, cleaner environment, and increased jobs.

An example of a specific benefit would be the compliance cost savings resulting from the deployment of advanced environmental-control devices to reduce powerplant emissions, including SO<sub>2</sub> and NO<sub>x</sub>. The benefit would be lower electricity cost. The overall economic value of even a small reduction in the cost to produce electricity is huge considering that domestic electricity sales are forecast to total 3,877 billion kilowatt-hours in 2010.

**Achievement** is the number of target goals reached and the degree to which they are achieved. An example is the achievement of cost and performance targets of systems and technologies within a planned time frame.

C&PS OBJECTIVES BY PROGRAM ELEMENTS	
Time Frame	Objectives
	<b>Technologies for Existing Plants</b>
2000	Complete the development, demonstration, and dissemination of technical, economic, and environmental results for environmental-control systems needed to meet Title IV requirements of the Clean Air Act.
2000	Develop a technology roadmap that leads to improved powerplant efficiency and performance through systems integration, advanced-combustion and emission-optimization control systems, and other techniques.
2005	Promote the enhancement of the technical performance of environmental-control systems to meet pending environmental regulations, including those associated with PM <sub>2.5</sub> , NO <sub>x</sub> reduction for ozone attainment, and HAPs.
2010	Foster the development of new, cost-effective advanced environmental-control technologies for achieving near-zero emissions of SO <sub>2</sub> , NO <sub>x</sub> , particulates, and HAPs, and for minimizing solid and liquid wastes.
2010	Develop plant efficiency and performance enhancement techniques that can be used domestically and internationally for direct reduction of CO <sub>2</sub> emissions and that will improve coal-fired powerplant competitiveness.
	<b>Near- and Mid-Term Development and Demonstration</b>
2001	Complete the Low-Emissions Boiler System Development Program and disseminate the results to prospective customers.
2005	Complete the demonstration projects conducted under the Clean Coal Technology Demonstration Program.
2005	Foster development of advanced gas turbine systems that use natural gas and are also capable of operating with coal- or biomass-derived fuel, to be introduced into commercial operation by 2010.
2010	Complete the development of a suite of power systems, including pressurized fluidized-bed combustion, integrated gasification combined cycle, indirect fired cycles, and gasification/fuel cell combined cycles for market readiness and as power modules for Vision 21.
2010	Complete the technology base necessary to ensure commercial viability of technologies that produce transportation fuels at a cost competitive with conventional petroleum products and with 20% less CO <sub>2</sub> emissions than current petroleum-process technologies.
2010	Ensure the commercial viability of technologies needed to convert solid feedstocks into finished fuels, chemicals, feedstocks, and carbon products at a competitive price and with minimal environmental impact.
	<b>Distributed Generation</b>
2000	Perform the systems, market, and cost analyses necessary to establish a strategic technology roadmap.
2005	Complete demonstration of the domestic and international commercial viability of new distributed power-generation technologies that use fossil fuels, including advanced fuel cells, heat engines, hybrids, and integrated heat and power systems.
2010	Enhance the technical, economic, and environmental performance of distributed power-generation technologies, and extend fuel capability to biomass and other CO <sub>2</sub> -neutral fuels to compete in the restructured power-generation market.
	<b>Vision 21</b>
2005 to 2010	Further develop existing gasification, gas cleanup, combustion, turbine, fuel cell, and coproduction technology to meet efficiency goals greater than 60% for coal-fired units and 75% for gas-fired units, with near-zero SO <sub>2</sub> , NO <sub>x</sub> , and particulate emissions.
2005 to 2010	Complete development of advanced materials, components, catalysts and sorbents, computational sciences, and other fundamental technologies required to support integration of modules into the Vision 21 fleet of energy plants.
2010	Ensure that specific enabling technologies have been identified, are available, and are market-ready to achieve the benefits of Vision 21.

Time Frame	Objectives
	<b>Carbon Sequestration Research</b>
1999	In conjunction with the Office of Energy Research, the Office of Fossil Energy will develop a science and technology roadmap that will describe various sequestration pathways.
2005 to 2010	Develop moderate-cost technology options for CO <sub>2</sub> management, which would include capture, separation, use, and disposal.
2010 to 2015	Develop effective technologies to integrate capture and sequestration of CO <sub>2</sub> with advanced power systems, and develop technological approaches that enhance the performance and efficiency of natural sinks.
2015	Develop technology options based on novel concepts, such as artificial photosynthesis, to achieve near-zero greenhouse gas emissions from fossil fuels, at low cost.
	<b>Advanced Research</b>
Ongoing	Continue to seek technology breakthroughs by pursuing research performed under University Coal Research, Small Business Innovative Research, and Historically Black Colleges and Universities/Other Minority Institution programs.
2005	Extend the materials, bioprocessing, and coal utilization science technology base by conducting evolutionary support research for the technical modules and product lines.
2010	Develop revolutionary technologies and processes that can substantially improve and advance power, environmental, and fuel systems. This new portfolio of advanced technologies will contribute to the achievement of Vision 21.
2015	Develop a series of “leapfrog” technologies (e.g., advanced CO <sub>2</sub> -management schemes, advanced hybrid processes and cycles, and smart systems).
	<b>International</b>
Ongoing	Introduce coal-intensive or coal-importing developing countries to advanced power systems technologies that reduce CO <sub>2</sub> and other emissions.
Ongoing	Assist U.S. industries in maintaining world leadership in fossil fuel technologies, consistent with sustainable development, climate and environmental goals, and U.S. economic competitiveness.
Ongoing	Promote U.S. goods and services in the international market.
Ongoing	Ensure transparency in energy trade.
Ongoing	Provide the appropriate regulatory framework for effective international trade.
	<b>Technical, Economic, and Environmental Systems Studies</b>
	<i>The Technical, Economic and Environmental Systems Studies support all of the other seven key elements in the Coal and Power Systems Program. A strategic goal is to generate information from systems studies that shape the framework and scope of the C&amp;PS strategic plan and provide insight on important energy and environmental issues to DOE management and stakeholders.</i>
2000	Complete assessments of pending environmental regulations, State and Federal utility restructuring legislation, and other policy, regulatory, and legislative issues that arise, to determine their effect on coal and power systems deployment.
2005	Develop a C&PS strategy consistent with the national strategy on greenhouse gas emissions.

A specific achievement could be the number of advanced technologies, products, and services resulting from the R&D program (e.g., clean coal technologies) developed for commercial readiness.

**Effectiveness** is the extent of the impacts made in achieving the target goals. An example is effectiveness in assisting U.S. industry to compete in the international market.

**Awareness** is the degree and extent to which changes in public perception of coal and fossil power are realized through the dissemination of fact-based information.

ACCOMPLISHMENTS

**Lower-cost and more effective SO<sub>2</sub>-control technologies for coal-fired powerplants** have been developed in partnership with industry, producing an installed base of 77 gigawatts, one-fourth of all U.S. capacity. The cumulative building and operating costs for these scrubbers through 1995 were reduced by \$50 billion because of this research. Typical emissions of SO<sub>2</sub> from a 500-MWe powerplant have dropped from 70,000 tons per year in 1970 to 20,000 tons per year in 1995.

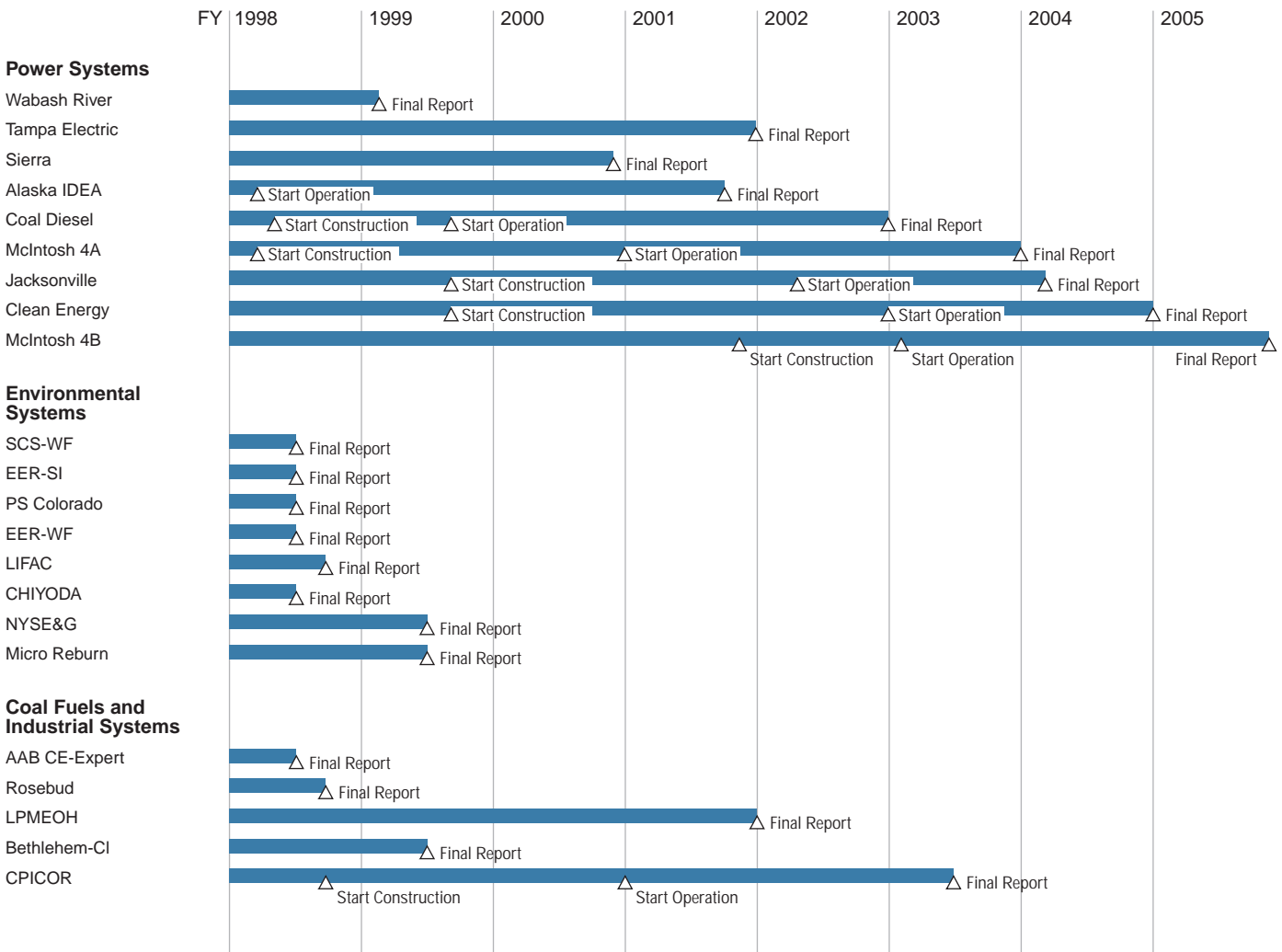
**A new generation of low-NO<sub>x</sub> combustors and postcombustion devices** has been developed by the Office of Fossil Energy (FE) in partnership with industry. Burner sales to date exceed \$750 million, and will approach \$4 billion by 2000. Similar NO<sub>x</sub> reductions would have been more costly using previously attainable control technology. Sales of postcombustion technologies (like selective catalytic reduction) are projected at over \$2.5 billion by 2000. Previously, this technology had cost twice as much as today's version.

**The technical, environmental, and operational database for commercial-scale utility atmospheric fluidized-bed combustion (AFBC)** was developed under the cost-shared FE-industry program. As a result of this 110-MWe repowering demonstration, the vendor was able to introduce a commercial line of AFBC boilers 3 years earlier than expected.

**In the first utility-scale demonstration of pressurized fluidized-bed combustion (PFBC),** a 70-MW plant achieved over 11,000 hours of operation and successfully demonstrated 90% to 95% SO<sub>2</sub> removal and NO<sub>x</sub> emissions in the range of 0.15-0.33 lb/10<sup>6</sup> Btu. This joint FE-Ohio Power Company project's successful operation is the basis for a project that will demonstrate a second-generation PFBC at twice this scale.



CLEAN COAL TECHNOLOGY DEMONSTRATION PROGRAM MILESTONES



**Over 600 MWe in integrated gasification combined-cycle (IGCC) power** is now in commercial service in the U.S. at three locations. The technology being demonstrated is 10% to 20% more efficient than conventional pulverized coal plants, achieves up to 98% SO<sub>2</sub> removal, and reduces NO<sub>x</sub> emissions to approximately 0.1 lb/10<sup>6</sup> Btu. This achievement was the result of the cost-shared government/industry Clean Coal Technology (CCT) Program partnership.

**A barrier to using the Nation's vast low-sulfur, low-energy-density western coal resources** is being addressed through two advanced, coal-upgrading

projects under the cost-shared CCT program. Both processes produce a stable coal product having low moisture content, low sulfur content, and a heating value of 12,000 Btu/lb. One process also produces a liquid product equivalent to No. 6 fuel oil. The products from these two projects are being sold to utility and industrial consumers. The technologies are being marketed actively worldwide, particularly in Asia.

**The environmental acceptability of industrial coal use** is being addressed under FE-industrial partnership demonstrations. For example, blast

furnace granular-coal injection technology demonstrated that 40% of the coke can be replaced with coal injected directly into a blast furnace. This process reduces the coke production requirement with the attendant reduction in SO<sub>2</sub>, NO<sub>x</sub>, and HAPs emissions.

**Numerous awards have been presented** to projects conducted under the FE-industry cost-shared CCT program for advancing coal-based technologies. Five Powerplant of the Year Awards have been presented by *Power Magazine* since 1991 to projects demonstrating advanced flue gas desulfurization, PFBC, and IGCC technologies.

PROGRAM STRATEGIES

The underlying strategic principle is to build on the technological successes already achieved by the Coal and Power Systems Program in order to develop very clean advanced electric power generation and transportation fuel production technologies. Three basic program strategies used to implement this principle are customer focus, resource optimization, and strategic partnering.

**Focusing on the customer-stakeholder.** A primary strategy is to listen to the customers’ needs and incorporate them into the program’s goals, objectives, and activities. To accomplish this, customer forums are established, utilizing mechanisms such as regional meetings, joint studies, and co-sponsorship of events.

Customers need easy access to accurate, reliable, usable, and relevant information to enable them to make

informed decisions. This requires an effective coordinated outreach effort.

Examples of outreach tools include conferences, workshops, regional forums, educational programs and materials, speaking engagements, multimedia presentations, and the Internet. Feedback from various stakeholders, customers, users, and interest groups helps measure the benefits and effectiveness of the outreach strategy.

**Optimizing resources.** Scarce fiscal resources must be used wisely and effectively. The focus is on optimizing resource use by leveraging existing funds through cost participation with other stakeholders, and making use of relevant and applicable results from other research programs through collaborative efforts.

An analysis of the potential return on the research investment will be used to establish funding priorities. In addition, multi-year cost profiles (as well as cost-sharing profiles) are used to plan investment requirements.

**Strategic partnering.** Partnering with industry and other key public- and private-sector stakeholders is essential to achieve program goals. Partnership arrangements with stakeholders include:

- Cost-sharing or cost participation with industry and other organizations
- Establishing diverse sources (including Historically Black Colleges and Universities/Other Minority Institutions) of collaborative and coordinated research and development activities aimed at achieving the program objectives within required time frames
- Establishing feedback mechanisms, such as industry forums, to assess progress and direction

With respect to cost-sharing and repayment arrangements with industry, appropriate terms depend on the maturity of the technology and reflect the sharing and management of risks.

*Demonstrating the success of converting coal to high-value, low-emission feedstocks, the innovative ENCOAL process plant near Gillette, Wyoming, now supplies industry with both solid and liquid fuels of superior quality. With a goal of 1,000 tons of coal processed per day, ENCOAL has supplied 5 million gallons of coal-derived liquid to eight industrial customers. It has delivered 17 unit trains of process-derived fuel, a low-sulfur, high-Btu solid product, to six major utilities. A large-scale commercial plant is now under development.*



COAL AND POWER

SYSTEMS TECHNOLOGY

The strategic focus of the C&PS program is on implementing eight key elements aimed at developing and deploying technology options for the changing energy landscape over the next two decades. These program elements are described below.

Four guiding principles are used to develop each key element:

1. Build on past R&D successes and experiences.
2. Build an essential portfolio of technologies including advanced, revolutionary, and “leapfrog” technologies.
3. Provide timely and effective dissemination of technology results.
4. Use analysis as a guiding tool in R&D.

TECHNOLOGIES FOR EXISTING PLANTS

**Cost-effective advanced environmental compliance.** Strategies are to pursue the development of technologies to reduce emissions of SO<sub>x</sub>, NO<sub>x</sub>, and fine particulates from powerplant flue gases; develop controls for hazardous air pollutants; reduce the quantity of solid waste generated; and improve disposal practices and promote the economic utilization of solid waste to meet existing and emerging environmental regulations for the utility sector.

**Improved plant efficiency and performance.** The program will invest in approaches that improve the efficiency and performance of the existing fleet of over 300 gigawatts of coal-fired power generation through (1) improved

systems integration, (2) advanced combustion technology, (3) advanced optimization and boiler control systems, and (4) reduced parasitic power consumption associated with environmental controls.

The goal is to make these systems flexible so they can be incorporated into existing powerplants as well as integrated into future plant designs.

NEAR- AND MID-TERM DEVELOPMENT AND DEMONSTRATION

**Clean Coal Technology demonstrations.** The strategy is to demonstrate highly efficient, low-emission, advanced coal technologies for electric power generation, environmental control, production of clean fuels, and industrial applications. Commercial-scale demonstration projects will be concluded delivering operational, technical, environmental, and economic performance know-how to industry.

**High-efficiency, ultra-clean coal- and natural-gas-power systems.** The strategy is to foster the development of (1) ultra-high-efficiency, environmentally superior, and cost-competitive advanced gas turbine systems for baseload applications; (2) low-emissions boiler systems to provide reliable, efficient, and environmentally superior alternatives to current technologies; and (3) technically, economically, and environmentally superior pressurized fluidized-bed combustion, integrated gasification combined cycle, indirect fired cycle, and gasification/fuel cell combined systems.

The potential efficiency of these systems ranges from 40% to nearly 70%. The challenge is to achieve these performance levels while providing electricity at a cost that is 10% to 20% lower than current generation plants.

STAKEHOLDER FEEDBACK

- Continue emphasis on power generation R&D
- Pursue R&D on retrofitable emission control systems
- Pursue R&D on coal fuels
- Pursue R&D on environmental aspects of coal production technology
- Solicit stakeholder input on R&D priorities for carbon sequestration
- Pursue industry-government-university partnerships in carbon sequestration research

**Advanced fuels production.** The program will seek the development and demonstration of technologies capable of (1) providing fuels, chemicals, and carbon products for use in all sectors of the economy and (2) converting raw solids into utility and boiler fuels and tailored feedstocks to produce chemicals and carbon products. The aim is to provide the Nation with the capability to economically produce transportation fuels, chemicals, and feedstocks from coal, natural gas, oil shale, biomass, and other carbonaceous resources. Technologies to produce hydrogen will also be pursued through cooperative efforts with other offices in DOE.

DISTRIBUTED GENERATION

This effort will foster the development and deployment of clean, reliable base-load power generation alternatives, such as fuel cells and heat engines, that can be integrated into systems capable of providing both heat and power for industrial and commercial customers. These systems are characterized by their range of sizes to meet distributed applications, high efficiencies of 50% to 70%, and extremely low pollutant emissions. The aim is to provide systems that can compete in the domestic utility market in areas where transmission is expensive or restricted, or where reliability is absolutely required. There is also potential for a significant market in developing countries.

VISION 21

**Develop technology to enable Vision 21.** Vision 21 is a set of flexible, high-efficiency modular systems of varying sizes that can be integrated and tailored to produce electricity and high-value, fossil-based commodities for domestic and international markets. Vision 21 systems will (1) be capable of producing electricity at an efficiency of over 60% with coal and 75% with gas at a cost that is 10% to 20% less than current systems, (2) offer choices for the economical production of fuels and chemicals, (3) have near-zero SO<sub>2</sub>, NO<sub>x</sub>, and particulate emissions, (4) provide options that will have no net CO<sub>2</sub> emissions, and (5) be fuel-flexible. R&D will focus on new enabling technologies such as low-cost oxygen- and hydrogen-separation membranes and high-temperature heat exchangers, as well as improving the performance and integration of gasifiers, advanced gas cleanup systems, advanced-combustion systems, hybrid systems, turbines, and coproduction technologies.



Chris Arend

*A Clean Coal Technology project demonstrates advanced electric power generation: two slagging coal combustors will burn pulverized coal in a Healy, Alaska, plant.*

The success of Vision 21 also depends on significant innovation in supporting technology areas, including materials and components, catalysts and sorbents, computational sciences, and advanced controls and sensors.

CARBON SEQUESTRATION RESEARCH

The goal is to provide a suite of cost-effective options that capture and sequester CO<sub>2</sub> emissions from fossil-fueled powerplants. This research focuses on (1) capture, separation, use, and/or disposal of CO<sub>2</sub> before it enters the atmosphere; (2) enhancement of the performance and efficiency of natural CO<sub>2</sub> sinks; and (3) novel techniques, such as artificial photosynthesis and other biotechnologies. This element of the program involves supporting science, as well as technology development and proof of concept verification.

ADVANCED RESEARCH

The program will seek new and innovative scientific approaches that are essential to achieving C&PS strategic goals. Advanced research pursues (1) **evolutionary** supporting research for product lines being developed, (2) **revolutionary** and innovative concepts that produce significant technological improvements in product lines, and (3) **leapfrog** or breakthrough technological concepts that respond to grand technical challenges (i.e., those challenges that, if overcome, can result in major, accelerated advancements toward achieving program goals).

INTERNATIONAL

The strategy is to advance the coal and power industry worldwide by working with U.S. and foreign partners to:

- **Maximize export opportunities** supporting domestic energy project developers in expanding international sales of energy technology by facilitating new market entry, expanding existing markets, and encouraging private investments, while removing potential barriers to investments. This includes the introduction of advanced power technologies that reduce carbon dioxide and other emissions into coal-intensive economies.
- **Provide leadership in international organizations.** All activities are driven by and support U.S. foreign policy objectives related to energy, environment, economic prosperity, and national security. Focus is on expanding international demand for U.S. coal and U.S. technologies.
- **Establish effective partnerships** that increase bilateral and multilateral R&D efforts; promote U.S. international technology transfer; support environmental cooperation; and encourage environmentally friendly development. This strategy will be accomplished through training and by providing information on clean power systems.

TECHNICAL, ECONOMIC, AND ENVIRONMENTAL SYSTEMS STUDIES

Analyses will be performed to shape the framework and scope of the C&PS program, and provide insight to FE stakeholders on energy and environmental issues. Among the most significant issues are (1) potential impacts of implementing the Clean Air Act Amendments of 1990 Title IV (production of SO<sub>2</sub> and NO<sub>x</sub>) and Title I (reduction of NO<sub>x</sub> to attain ozone National Ambient Air Quality Standards [NAAQS]); (2) pending revisions of the NAAQS for fine particulates (PM<sub>2.5</sub>) and ozone; (3) reduction of hazardous air pollutants particularly mercury; (4) climate change strategies; and (5) electricity-restructuring legislation.

PROGRAM BENEFITS

Investments made in C&PS by government and industry are projected to reap enormous environmental, economic, and energy security benefits. The C&PS program is projected to result in the creation of over 700,000 jobs per year and about \$335 billion in new domestic economic benefits through 2010. Tables containing a detailed summary of these projected benefits are shown below and on the next page.

**Emission and cost reductions.** Between the years 2000 and 2015, 70% reductions are projected for SO<sub>2</sub>, NO<sub>x</sub>, and HAPs emissions from existing powerplants, while environmental compliance cost reductions for meeting existing and future regulations are expected to average about \$5 billion per year through 2010 and could exceed \$7 billion per year between 2010 and 2020.

**Boost to the U.S. economy.** Savings in the cost of electricity would have a beneficial effect on the U.S. economy. Over the first 10 years (through 2010), the Gross Domestic Product (GDP) is expected to increase by slightly over \$137 billion, generating roughly 140,000 jobs per year.

**Capturing U.S. and global markets.** Cost-competitive advanced technologies will equip U.S. manufacturers to capture a significant share of U.S. and global markets for power generation equipment. For the 20 years leading up to 2020, domestic sales are expected to have an economic impact of about \$65 billion and generate over 100,000 jobs per year. During this same time period, international sales could potentially bring in revenues of over \$235 billion and could support about 500,000 jobs per year.

DERIVED PUBLIC BENEFITS FROM COAL AND POWER PROGRAM

Time Frame	Program Drivers	Public Benefits
Near Term (2000–2004)	Environmental Improvement	Meet existing environmental standards with lower-cost environmental technology (CCT) (\$25B total savings) and higher efficiency system (ATS)
	Greenhouse Gas/Climate Change	GHG reduction (through efficiency increase >60% with ATS and fuel cells and biomass cofiring) “voluntary contributions”
Mid Term (2005–2010)	Environmental Improvement	Achieve pending new environmental standards for existing plants with new/improved/low-cost environmental technologies (\$6B/yr)
	Greenhouse Gas/Climate Change and Environmental Impact	Deployment of first wave of new advanced powerplants (e.g., LEBS at 42% efficiency; 29% CO <sub>2</sub> reduction) can replace the aging fleet of powerplants (3,500 plants over 30 years old in 1998); replacement potential with other advanced power systems is 70% of the current 300-GWe coal capacity by 2010; 34-GWe new additions with coal by 2015; CO <sub>2</sub> rate reduction of 42% through efficiency increase, incremental improvements in pollutant reduction of 1/4 to 1/10 NSPS
	Energy Security	Energy security and reduced emissions in transportation sector through use of enhanced diesel fuel
Long Term (2011–2015)	Environmental Improvement	Additional \$6B/yr savings in environmental compliance; reduced emissions and increased efficiency in fuel use in transportation sector
	Climate Change	Reduced rate of CO <sub>2</sub> emissions via increased efficiency (clean coal, ATS, fuel cells); established viability of CO <sub>2</sub> sequestration with coal and other fossil fuels as energy source for power/fuels

BENEFITS SUMMARY OF FOSSIL ENERGY'S COAL AND POWER SYSTEMS PROGRAM

	2001–2005	2006–2010	2011–2015	2016–2020
<b>Domestic Power System New Capacity—Coal &amp; Gas (GW/5yr)</b>	93	56	84	57
Commercialization of Power Systems (\$mm/5 yr)	19,958	11,226	19,297	14,108
Jobs Created (job years/year)	163,656	92,055	158,235	115,686
<b>Foreign Power System Capacity (GW/5 yr)</b>	214	230	272	256
Commercialization of Power Systems (\$mm/5 yr)	48,587	54,522	66,777	67,522
Jobs Created (job years/year)	383,746	432,413	532,904	539,013
<b>Cumulative Production Capacity—Coal Liquids (mm bbl/day)</b>	0	0	0.15	0.54
Commercialization of Coal Liquids Technology (\$mm/5 yr)	0	0	1,158	4,316
Jobs Created (job years/year)	0	0	1,586	5,914
<b>Macroeconomic Benefit of Lower Priced Electricity</b>				
Contribution to GDP (\$mm/5 yr)	59,143	78,450	Unknown	Unknown
Jobs Created (5 Year Average Change from Base) (job years/year)	117,404	165,856	Unknown	Unknown
<b>Direct Employment in C&amp;PS R&amp;D Program</b>				
Dollars Invested in R&D (\$mm/5 yr)	4,986	4,986	4,986	4,986
Jobs Created (job years/year)	40,882	40,882	40,882	40,882
<b>Environmental Compliance Cost Savings Due to R&amp;D</b>				
Dollars Saved (\$mm/5 yr)	19,800	33,000	36,500	36,500
<b>TOTAL IMPACT OF FE C&amp;PS PROGRAM</b>				
Economic (\$mm/5 yr)	152,474	182,184	128,717*	127,432*
Jobs Created (job years/year)	705,689	731,207	733,608*	701,495*

\* Benefit estimates appear to decline from 2011 through 2020 because the macroeconomic benefits of lower-priced electricity have not been forecast, since they are unknown. If those benefits had been estimated, the benefits may not have declined from 2010.

Reduced dependence on foreign oil.

A U.S. coal-conversion industry could reduce dependence on foreign oil supplies, thus increasing the Nation's oil security while helping reduce the U.S. energy trade deficit, and capturing a share of what could be the largest new job-creating sector of the economy.

If, for example, domestic production of liquid fuels could be increased by just 1 million barrels per day, the balance of payments would be reduced by \$250 billion over the period 2015 to 2030. These savings can be achieved through successful strategic R&D investments in advanced liquefaction, as well as domestic enhanced oil-recovery technologies.

Reduced greenhouse gas emissions.

By 2020, deployment of more efficient power systems *globally* could reduce greenhouse gas emissions by nearly 150 million tonnes (MMT)/year of carbon. The goal set for FE-sponsored sequestration options is to be able to offset all growth in CO<sub>2</sub> emissions from U.S. power generation after 2010.